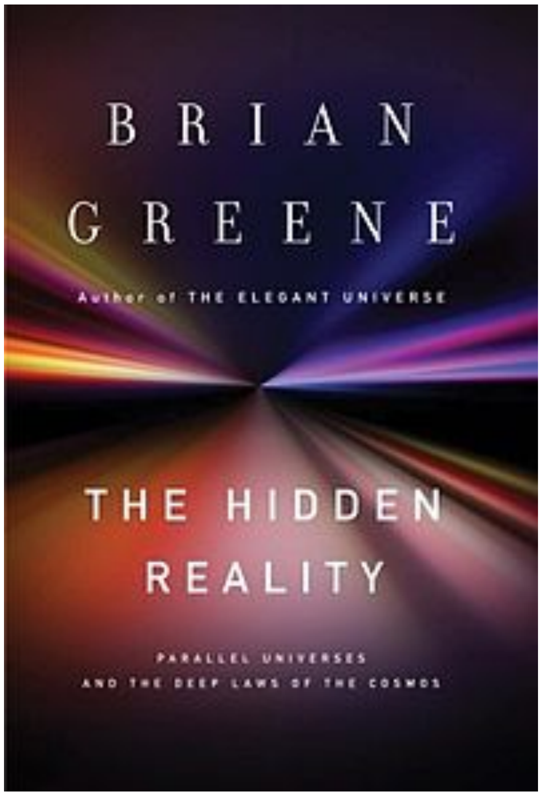
Chapter 20

Capacitors, Resistors and Batteries

Brian Greene, Nov 6 @ 7pm

Elliott Hall of Music



Free seating pass required for entry

http://www.convocations.org/portfolio/brian-greene-11-6-14/#sthash.KqvAENA9.dpuf

Announcements

EXAM II is Tuesday

8-10 PM – TUESDAY, Nov. 4 in Elliot Hall of Music

Material: Chapters 17, 18, and 19 in the book.

How to Study:

Practice Exam + Solutions + Eqn Sheet is on BBL.

(Note the practice exam has some
Ch 20 material, but your exam will not)

Find the WebAssign Extended Practice Problems
- not for credit, but you get 50 tries for ALL questions in Ch 17-19

Last Time

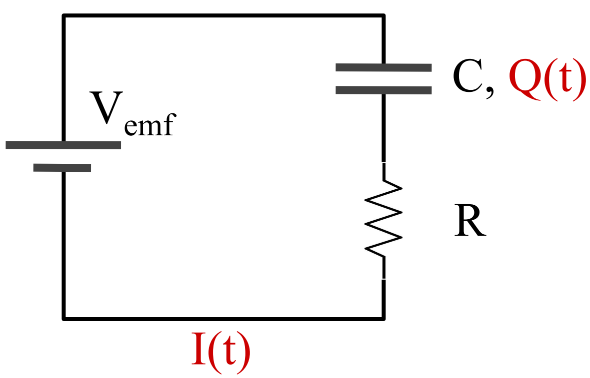
- Solving for Q(t) and I(t) in an RC circuit
- The "time constant" of an RC circuit is RC

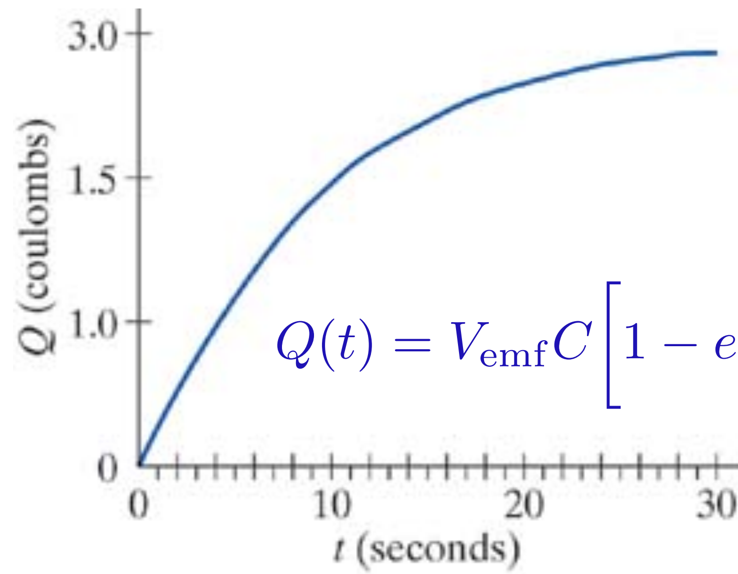
RC Circuit: Summary

$$Q = CV$$

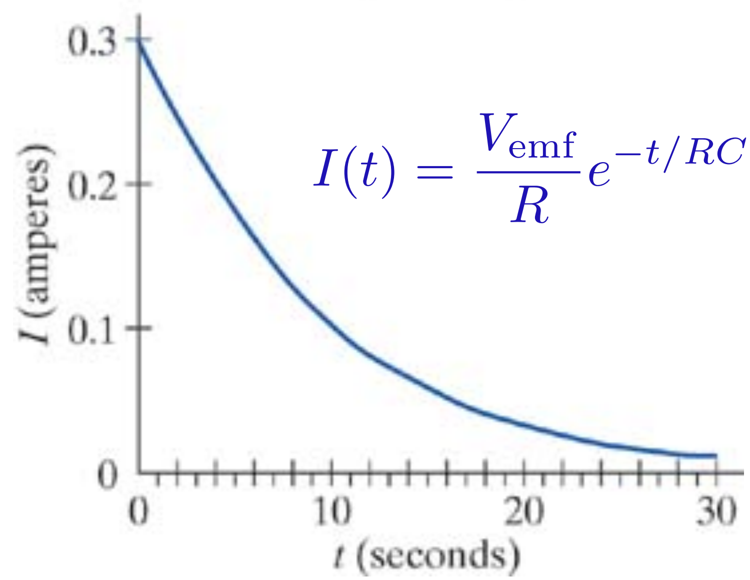
$$V = IR$$

$$I = \frac{dQ}{dt}$$





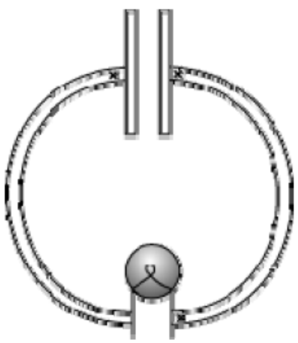
$$Q(t) = V_{\mathrm{emf}} C \left[1 - e^{-t/RC}\right]$$

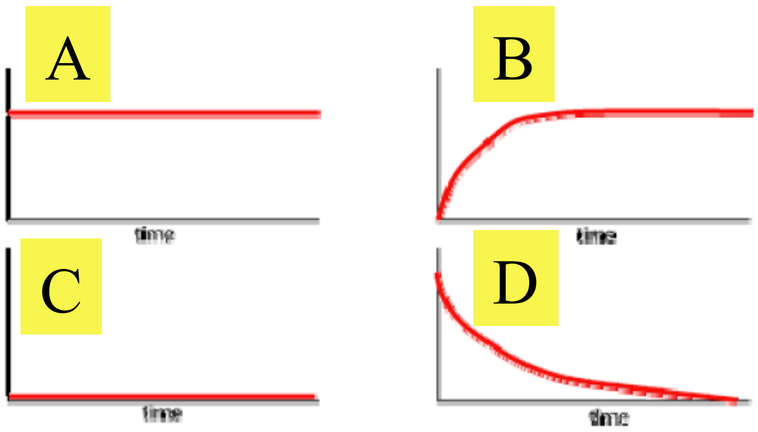


$$I(t) = \frac{V_{\mathrm{emf}}}{R} e^{-t/RC}$$

Clicker Q. 1

Capacitor initially charged. Which graph shows CURRENT vs TIME while DISCHARGING?





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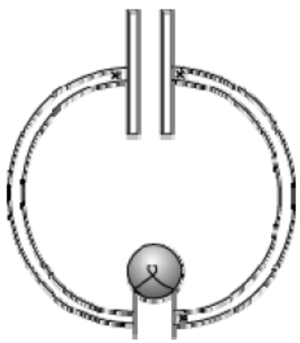
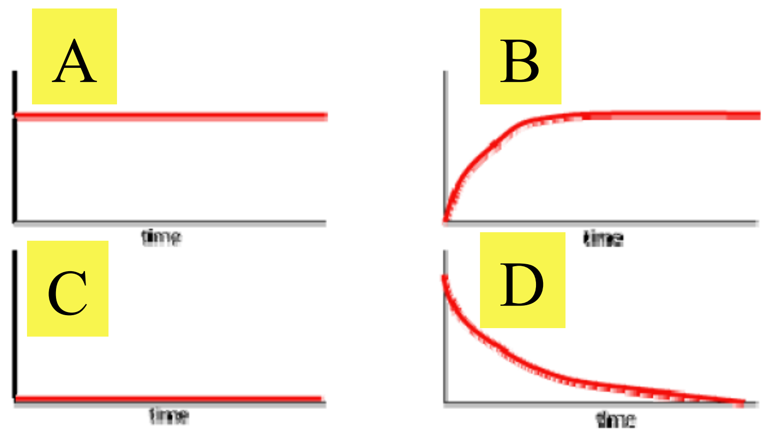
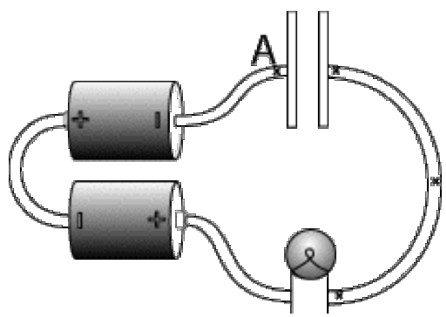


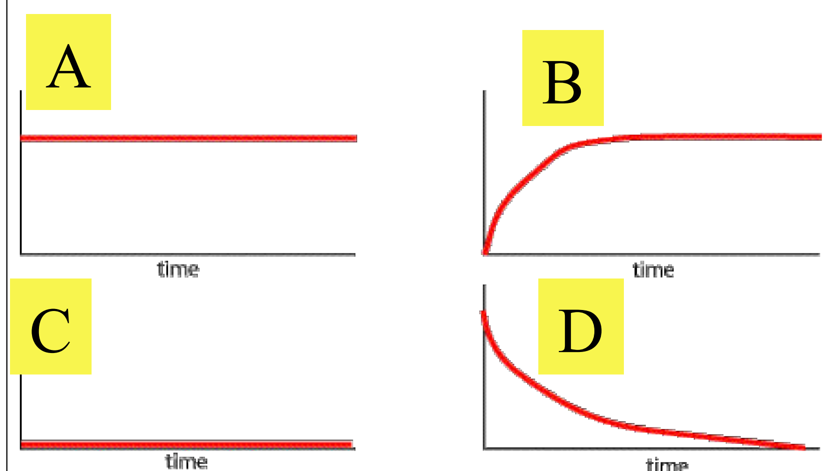


D

Capacitor initially uncharged. Which graph shows the magnitude of the
POTENTIAL DIFFERENCE across the LIGHT BULB FILAMENT while CHARGING?

Clicker Q. 2





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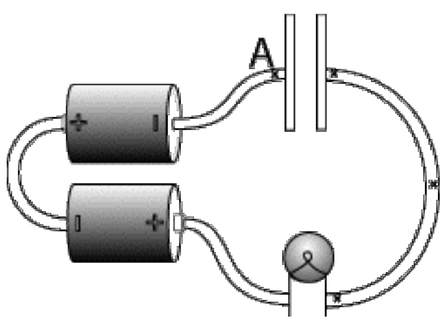
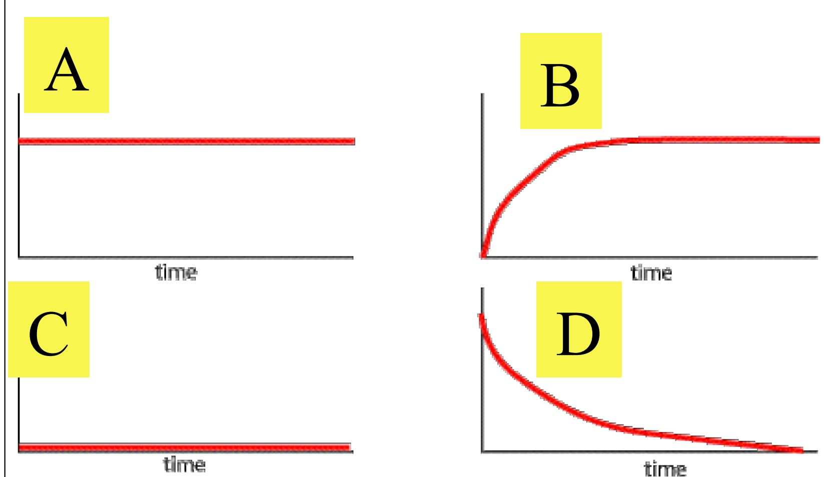


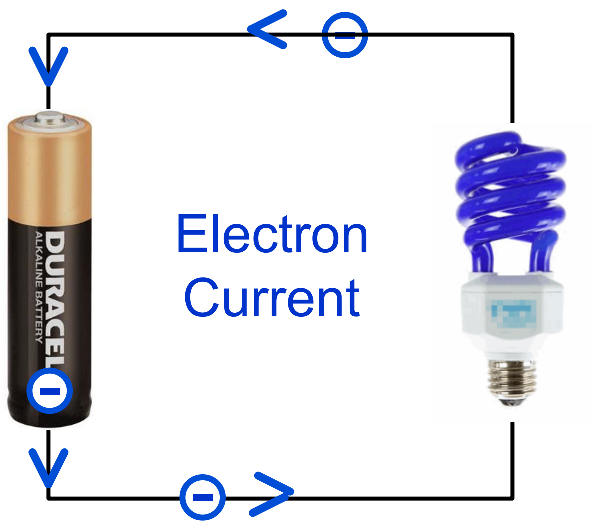
Clicker Q. 2



Today

- Ohm's Law
- Series and Parallel Resistors
- Series and Parallel Capacitors
- Ammeters, Voltmeters, Ohmmeters, Oh my!

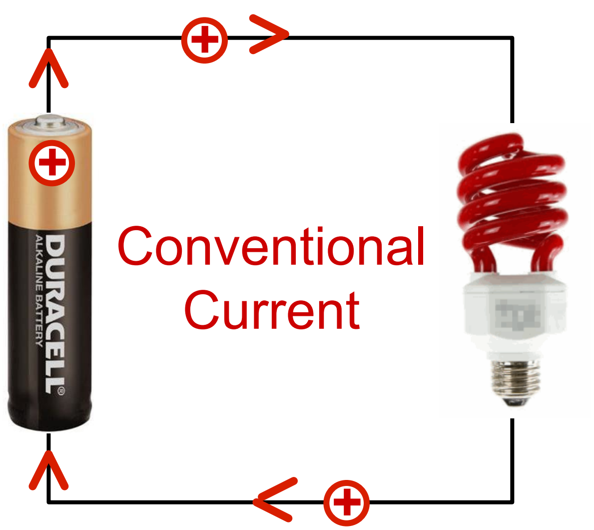
Conventional Current and Electron Current



Electron Current:

$$i = nA\bar{v} \;\; = \left[\frac{\text{electrons}}{\text{second}}\right]$$

Square Brackets [ ]
Mean "Units"



Conventional Current:

$$I = |q|nA\bar{v} = \left[\frac{\text{Coulombs}}{\text{second}}\right]$$

$$= \left[\text{Amperes}\right]$$

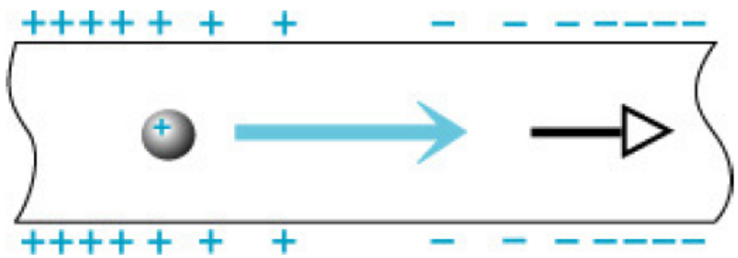
Blast from the Past:
Lecture 12

Current Density & Conductivity

$$I = |q| n A \bar{v}$$

$$\bar{v} = u\bar{E}$$

$$\vec{J} = \sigma \vec{E}$$



carrier density

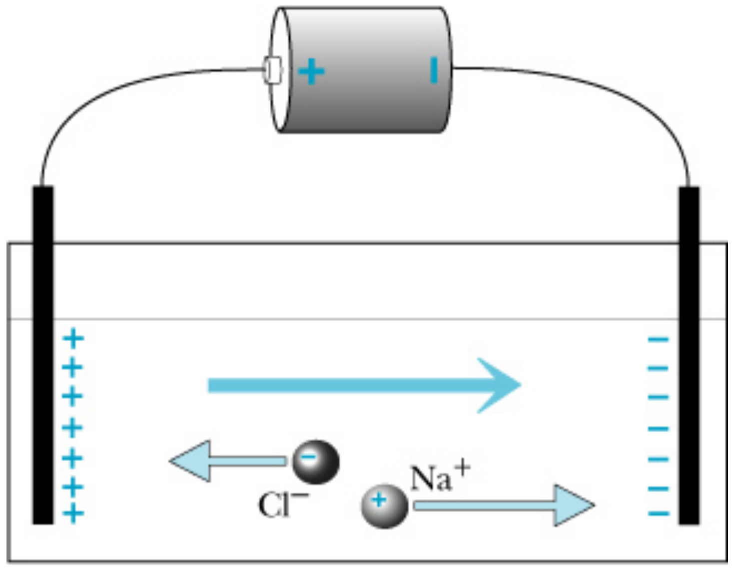
carrier charge

The conductivity is a material-dependent quantity: $\sigma = |q|\, n\, u$

mobility

The current density has magnitude $J = I / A$

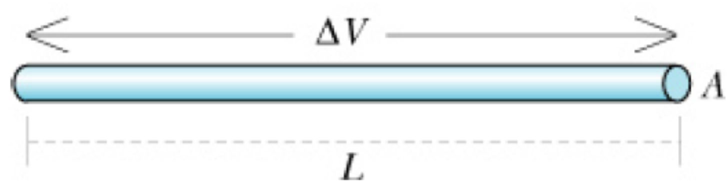
Conductivity with two kinds of charge carrier



$$\boxed{\sigma = |q_1| n_1 u_1 + |q_2| n_2 u_2}$$

Definition of Resistance

$$R = \frac{L}{\sigma A}$$



Important special case: if the conductivity remains constant regardless of how much current flows, then we call the material "ohmic" and any piece of the material obeys "Ohm's Law":

$$I = \text{constant} \ \ \text{x} \ \ |\Delta V|$$

Non-ohmic examples: diodes, capacitors, batteries.

"Ohmic" Resistors

$$|\Delta V| = I\ R$$

$$R = \frac{L}{|q|\,n\,A\,u}$$ *depends on both material properties and geometry*

Never write $V = I\ R$ *because …*

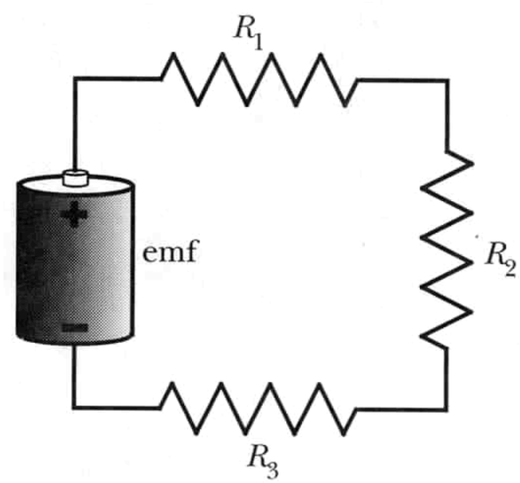
… what you really mean is $|\Delta V| = I\ R$

Series and Parallel

Series: One right after the other.
(Same current through each)

Parallel: Elements are “next to” each other.
(Same voltage across each)

Series Resistance



$$\Delta V_{\text{batt}} + \Delta V_1 + \Delta V_2 + \Delta V_3 = 0$$

$$emf - R_1 I - R_2 I - R_3 I = 0$$

$$emf = R_1 I + R_2 I + R_3 I$$

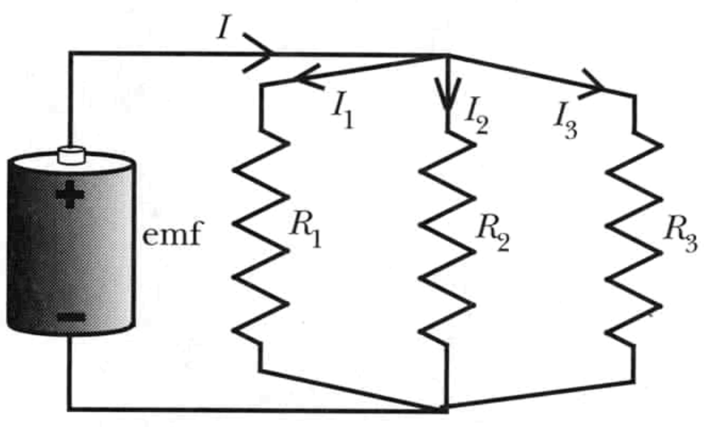
$$emf = (R_1 + R_2 + R_3)\, I$$

$$emf = R_{\text{equivalent}}\, I \;, \quad \text{where} \quad \boxed{R_{\text{equivalent}} = R_1 + R_2 + R_3}$$

For resistors made of the same material and with the same *A* it follows straight from the definition of resistance:

$$R = \frac{L}{\sigma A}$$

Parallel Resistance



$$I = I_1 + I_2 + I_3$$

$$I = \frac{emf}{R_1} + \frac{emf}{R_2} + \frac{emf}{R_3}$$

$$I = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) emf = \frac{emf}{R_{equivalent}}$$

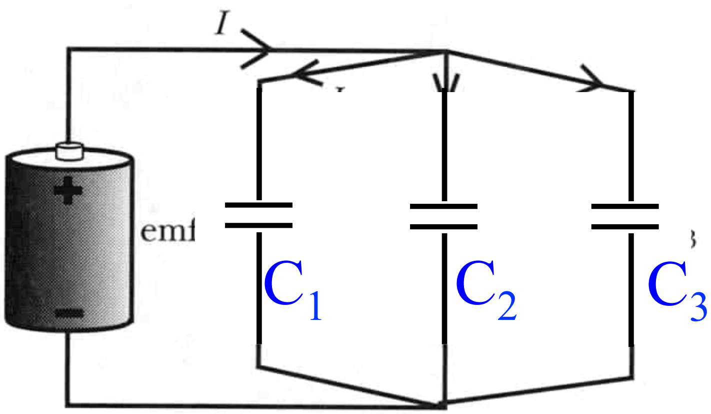
$$\boxed{\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

For resistors made of the same material and with the same A it follows straight from the definition of resistance:

$$R = \frac{L}{\sigma A} \longrightarrow \frac{1}{R} = \frac{\sigma A}{L} \qquad A_{equivalent} = A_1 + A_2 + A_3$$

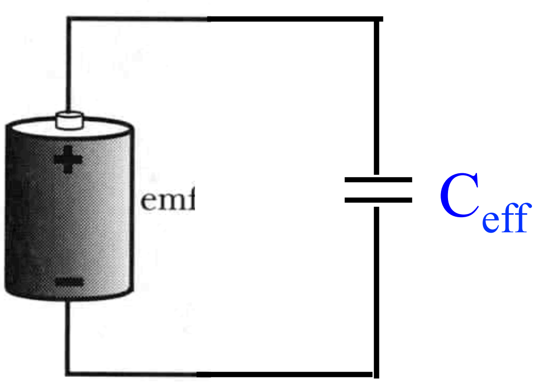
Parallel Capacitors

$$C = \frac{\varepsilon_0 A}{s}$$



$$C_{eff} = C_1 + C_2 + C_3$$

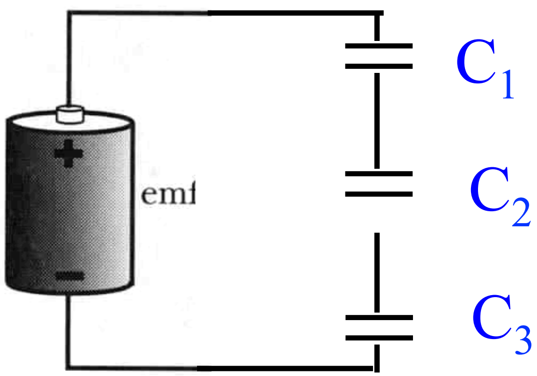
Equivalent to:



Parallel Capacitors ADD

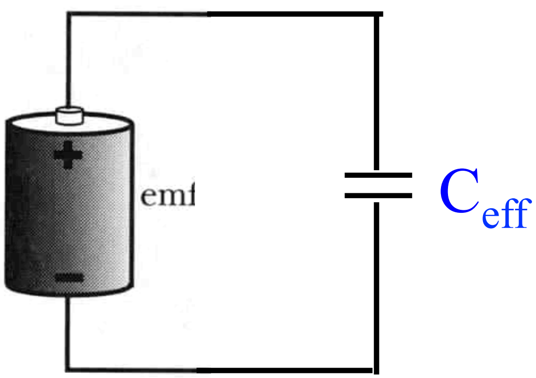
Series Capacitors

$$C = \frac{\varepsilon_0 A}{s}$$



$$\frac{1}{C_{\text{eff}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Equivalent to:



Resistors and Capacitors

Resistors in Series

$$R_{\text{eff}} = R_1 + R_2$$

ADD

Capacitors in Parallel

$$C_{\text{eff}} = C_1 + C_2$$

Resistors in Parallel

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Capacitors in Series

$$\frac{1}{C_{\text{eff}}} = \frac{1}{C_1} + \frac{1}{C_2}$$

iClicker Question

time constant = RC

Ammeters, Voltmeters and Ohmmeters

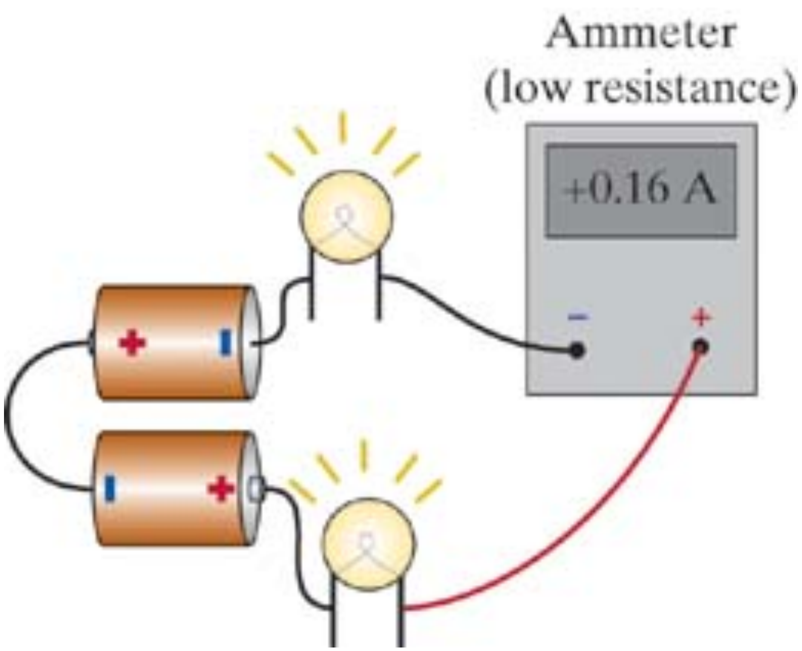
Ammeter: measures current I *(Amps)*

Voltmeter: measures voltage difference ΔV *(Volts)*

Ohmmeter: measures resistance R *(Ohms)*

Ammeter Design: r_{int}

Ammeter is inserted in series into a circuit – measured current flows through it.

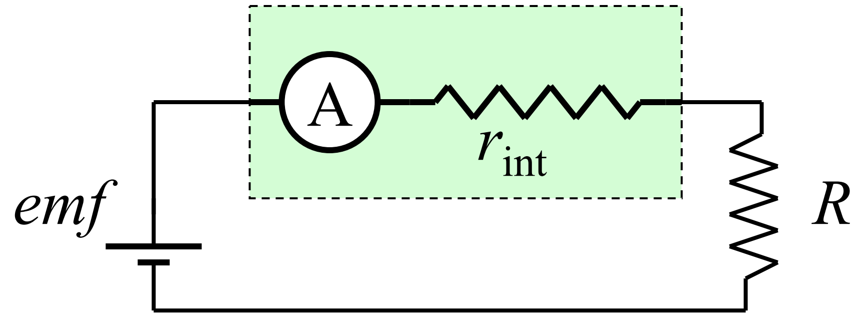


You have to get in the flow to measure the current.

http://www.ipswichriver.org/river-flow/measuring-river-flow/

Ammeter Design: r_{int}

Ammeter is inserted in series into a circuit – measured current flows through it.



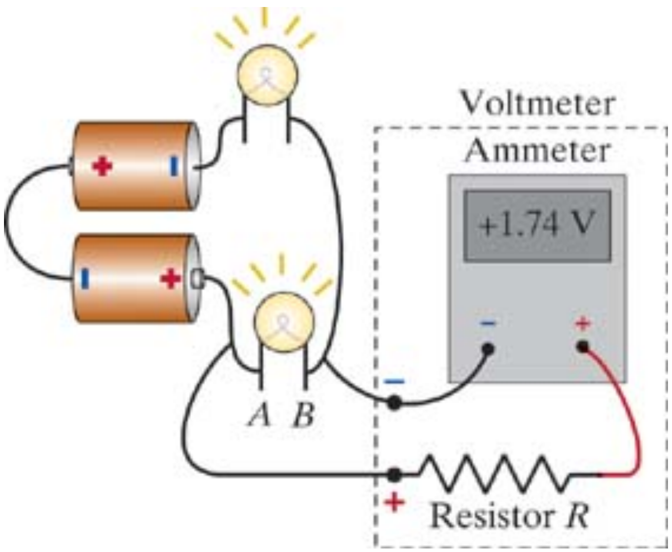
No ammeter: $emf - RI = 0 \longrightarrow I = \dfrac{emf}{R}$

With ammeter: $emf - r_{int}I - RI = 0 \longrightarrow I = \dfrac{emf}{R + r_{int}}$

Internal resistance of an ammeter must be very small

Voltmeter

Voltmeters measure potential difference



ΔV_{AB} – add a series resistor to ammeter

$$\boxed{I = \frac{\Delta V}{R}}$$

Measure I and convert to $\Delta V_{AB}=IR$

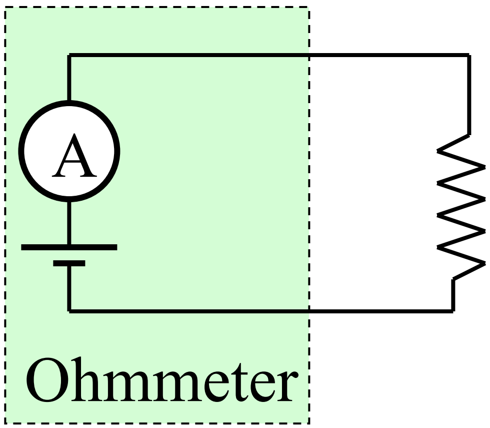
Voltmeter needs high internal resistance.

Connecting Voltmeter:

Higher potential must be connected to the '+' socket and lower one to the '-' socket to result in positive reading.

Ohmmeter

How would you measure R?



$$R = \frac{emf}{I}$$

$$\boxed{I = \frac{emf}{R}}$$

Ammeter with a small voltage source

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